TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE DIRECT-STRESS FATIGUE STRENGTH OF 17S-T ALUMINUM ALLOY

THROUGHOUT THE RANGE FROM 1/2 TO 500,000,000 CYCLES OF STRESS

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SUMMARY

Fatigue tests were conducted on six specimens made
from 3/4-inch-diameter 17S-T rolled-and-drawn rod for the
purpose of obtaining additional data on the fatigue life
of the material at stresses up to the static strength.
The specimens were tested in direct tension using a stress
range from zero to a maximum in tension. A static testing
machine was used to apply repeated loads in the case of
the first three specimens; the other three specimens were
tested in a direct tension-compression fatigue machine.

The direct-stress fatigue curve obtained for the ma-
terial indicates that, in the range of stresses above
about two-thirds the tensile strength, the fatigue strength
is higher than might be expected by simply extrapolating
the ordinary curve of stress plotted against number of
cycles determined at lower stresses.

INTRODUCTION

Fatigue-test results are ordinarily plotted with
stress as ordinates and number of cycles as abscissas.
The fatigue-strength curves for aluminum alloys usually
cover a range of cycles starting at some value around
50,000 and extending to about 500,000,000. The larger of
these two numbers is an arbitrary limit used to define
endurance limit; and the smaller is a value representing
limitations imposed by capacity of testing equipment, ex-
cessive yielding of material in specimens, and various
other practical considerations. For some applications of
aluminum alloys, useful engineering information would be
provided by extending the curves backward to smaller num-
bers of cycles and higher stresses. Such an extension of
a curve is difficult, however, because some of the stresses
involved exceed the yield strength of the material with

the result that there is considerable yielding of the
specimen, and it is therefore difficult to maintain the
loading conditions constant during testing. In the case
of bending-fatigue tests there is the additional diffi-
culty of accurately determining the extreme fiber stress
after yielding begins.

In order to avoid some of these difficulties it was
decided to limit this investigation to direct-stress fa-
tigue tests for cycles of stress ranging from zero to a
maximum in tension (stress ratio: minimum/maximum = 0).
It was further decided to test each of the most highly
stressed specimens in an ordinary Amsler static testing
machine using a series of repeated loadings; each loading
was applied by the operator in the manner that he would
apply an ordinary static loading. This scheme of testing
would not be practical, of course, for a large number of
tests, but it offered an opportunity to complete the
fatigue curve without the necessity of developing any
specialized testing equipment for the range of low num-
bers of cycles. The material selected was 17S-T rolled-
and-drawn rod for which a direct-stress fatigue curve for
zero stress ratio was already available starting at about
100,000 cycles.

The object of this investigation was to obtain ad-
ditional direct-stress fatigue-strength data for 17S-T
so that the fatigue-strength curve could be plotted for
the full range of numbers of cycles from static loading
to the endurance limit.

MATERIAL

The material used for this investigation was 3/4-inch-
diameter 17S-T rolled-and-drawn rod marked P-301. The
direct-stress fatigue curve for a stress ratio of zero,
as determined on the direct tension-compression testing
machines (reference 1, fig. 5) was already available at
the beginning of this investigation and is shown in fig-
ure 1. It will be noted that this curve covers the range
of cycles from about 100,000 to about 500,000,000, a
range commonly covered in conventional fatigue testing of
aluminum alloys. The chart on which this curve is plotted
does not provide room to extend the curve back as far as
desired into the low numbers of cycles. For this reason
a more condensed chart is shown in figure 2 in which the

full range of cycles from 1/2 (static loading) up to
500,000,000 (endurance limit) can be plotted. This chart
shows clearly that a considerable portion of the fatigue
curve was undefined by the existing data. This undefined
portion of the curve was, of course, the subject of this
investigation.

The tensile strength of the material represents the
end point of the fatigue curve and therefore assumes con-
siderable importance in this investigation. The value used
in this investigation (60,970 lb/sq in.) was determined
by conducting a static ultimate-load tensile test on one
of the regular specimens that had been prepared for the
fatigue tests. The Amsler autographic diagram taken on
this specimen showed a first departure from the straight
line at 38,400 pounds per square inch, which is an approx-
imate indication of the yield strength.

PROCEDURE

Tests in this investigation were made on specimens
of the type illustrated in figure 3, which is the type of
specimen ordinarily used in the direct tension-compression
fatigue testing machine. After they had been machined,
all specimens were carefully polished with strokes paral-
lel to the axis of the specimen. Care was taken in all
tests to avoid any scratching or marking of the surfaces
of the reduced portion of the specimen.

Two of the tests, in addition to the one for the
tensile-strength determination, were made in a 20,000-
pound-capacity Amsler testing machine with a load range
of 2000 pounds. These specimens had a nominal minimum
diameter of 0.200 inch. They were tested by repeatedly
applying and releasing a load equal to a predetermined
percentage of the tensile strength of the material. The
first specimen was tested at 98 percent of the tensile
strength and failed after 76 applications of the load.
The second specimen was loaded to 92 percent of the ten-
sile strength and showed no evidence of failure after
2000 applications of the load. The time required to test
this specimen to failure was considered prohibitive, and
the test was discontinued.

Three specimens were tested in the direct tension—compression fatigue—testing machine in the usual manner, except that special attention was given to the elimination of the effects of yielding in the specimens because of the high stresses encountered. It is common practice in testing specimens in the direct tension—compression fatigue machine to check the load after the first few cycles in order to make sure that yielding of the specimen or other factors have not changed the loading. In these tests at high stresses yielding of the specimen was expected to be of considerable importance, and the specimen was deliberately preloaded in the machine for several minutes and the load adjusted afterward to avoid any reduction in the load during the test because of progressive yielding of the specimen.

The first of the three tests in the tension—compression fatigue—testing machine was made on a specimen with a nominal diameter of 0.200 inch, but it was decided on subsequent specimens to reduce the diameter to a nominal diameter of 0.160 inch in order to reduce the load on the testing machine. The reduction of the minimum diameter of the specimen was made without altering any of the other dimensions shown in figure 3.

RESULTS AND DISCUSSION

Table I presents a complete summary of the data obtained in this investigation. These data have been plotted in the form of an S—N curve in figure 4. It will be noted that this curve covers the complete range of cycles from static loading to the endurance limit, as intended, and that the test results obtained on the Amsler testing machine seem to agree very well with the results from the direct tension—compression fatigue—testing machine. It will be further noted that the newly defined portion of the fatigue curve connects reasonably well with the previously determined portion of the curve, although the transition is a rather abrupt change in direction of the curve. Perhaps the most notable feature of the complete curve is that the fatigue strength of the material in the range of stresses above about two—thirds the tensile strength is considerably greater than one might expect by simply extrapolating the ordinary S—N curve determined at lower stresses.

CONCLUSION

The direct-stress fatigue curve shown for the 3/4-inch-diameter 17S-T rolled-and-drawn rod indicates that in the range of stresses above about two-thirds the tensile strength the fatigue strength is higher than might be expected by simply extrapolating the ordinary curve of stress plotted against number of cycles determined at lower stresses.

Aluminum Research Laboratories,
    Aluminum Company of America,
        New Kensington, Penna., April 23, 1942.

REFERENCE

1. Timplin, R. L.: The Fatigue Properties of Light Metals and Alloys. A.S.T.M. Proc., vol. 33, pt. II, 1933; pp. 364-380.

TABLE I.- SUMMARY OF DIRECT-STRESS FATIGUE TEST DATA ON

3/4-INCH DIAMETER 17S-T ROLLED-AND-DRAWN ROD

$$\left[\text{Stress ratio:} \quad \frac{\text{minimum}}{\text{maximum}} = 0 \right]$$

Specimen marked	Nominal diameter (in.)	Cross-sectional area, A (sq.in.)	Type of machine (a)	Maximum load, P_{max} (lb)	Maximum stress		Total number of cycles
					P_{max}/A (lb/sq in.)	Percentage of tensile strength	
P-301-16-1	0.1986	0.0310	A	1890	60,970	100	1/2
P-301-16-2	.1998	.0314	A	1876	59,750	98	76
P-301-16-3	.1983	.0309	A	1733	56,090	92	[b]2,000
P-301-16-5	.1602	.0202	T-C	1114	55,150	91	19,100
P-301-16-4	.1985	.0309	T-C	1548	50,100	82	54,200
P-301-16-6	.1591	.0199	T-C	886	44,500	73	75,700

[a]A represents an Amsler 20,000-lb capacity static testing machine, 2000-lb range; and T - C represents a tension-compression fatigue-testing machine.
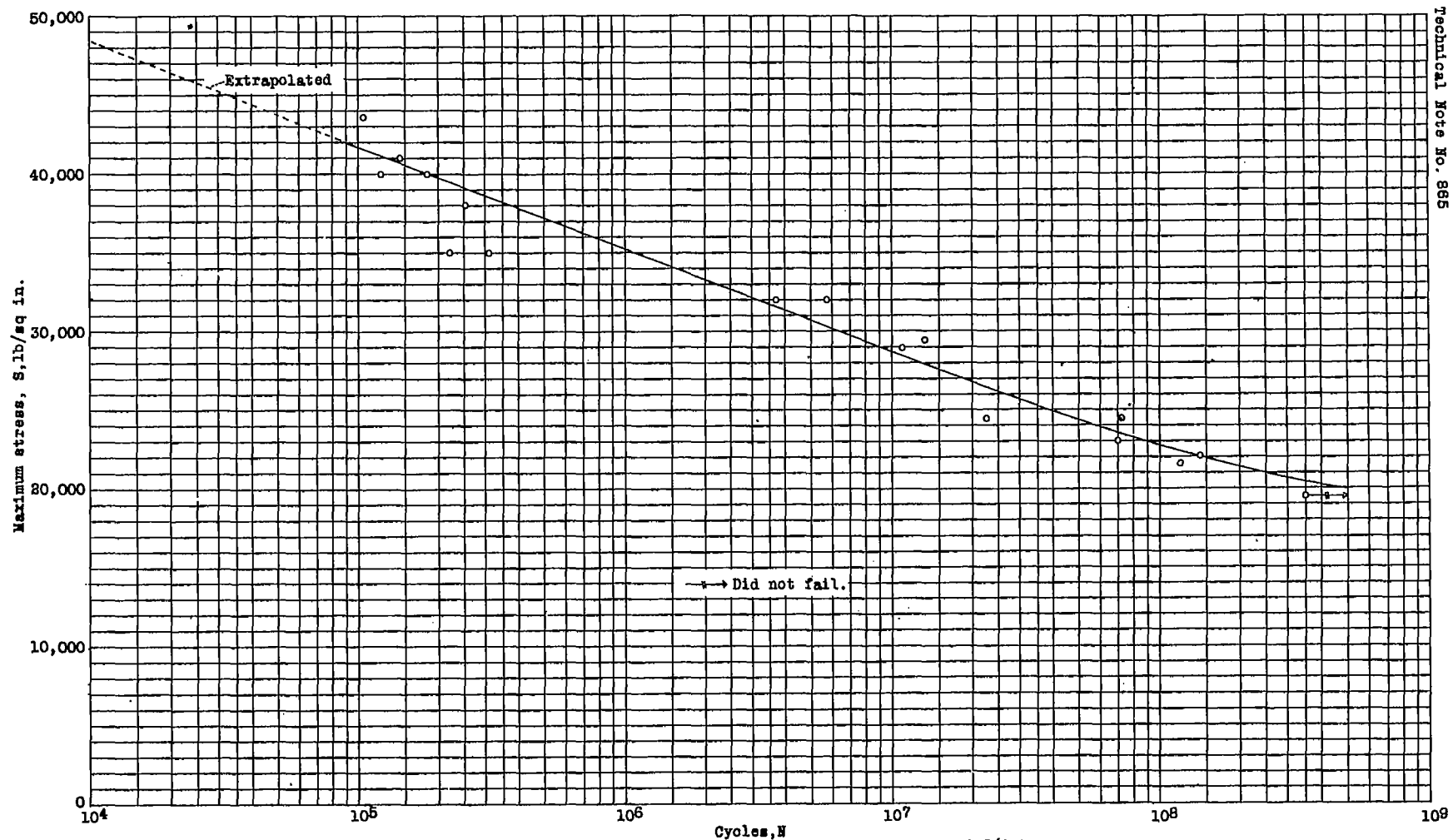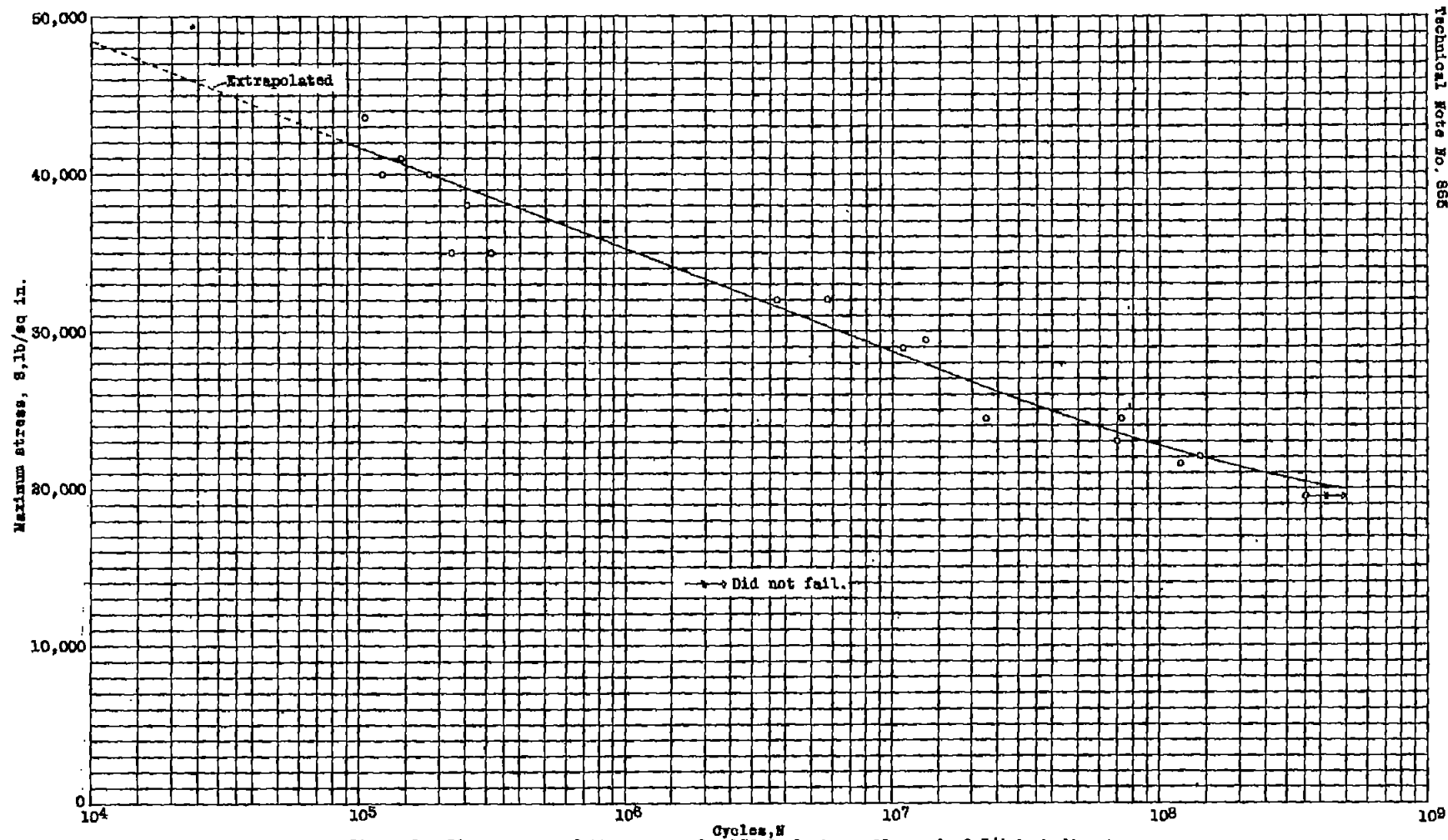
[b]Did not fail.

Figure 1.- Direct-stress fatigue curve for 178-T aluminum-alloy rod of 3/4-inch diameter.
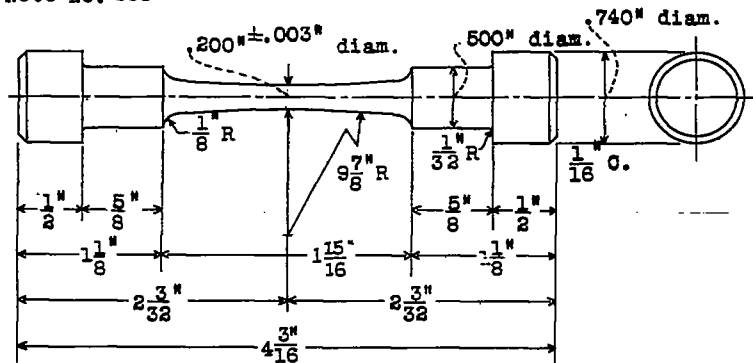Nominal ratio of minimum to maximum stress is equal to zero.

Fig. 1

Figure 1.- Direct-stress fatigue curve for 178-T aluminum-alloy rod of 3/4-inch diameter. Nominal ratio of minimum to maximum stress is equal to zero.

Fig. 1

Figure 3.- Fatigue specimen used in direct tension-
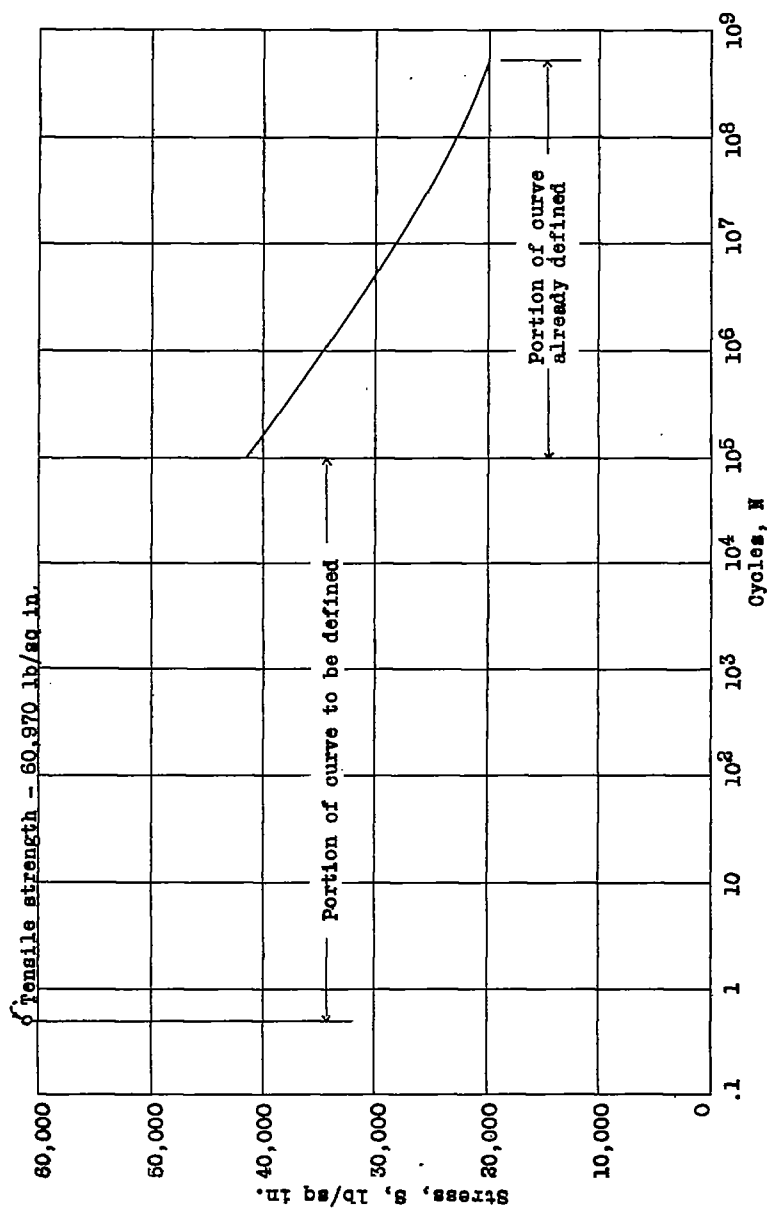compression machine.

Figure 2.- Fatigue strength of 17S-T aluminum alloy rod. Nominal ratio of minimum
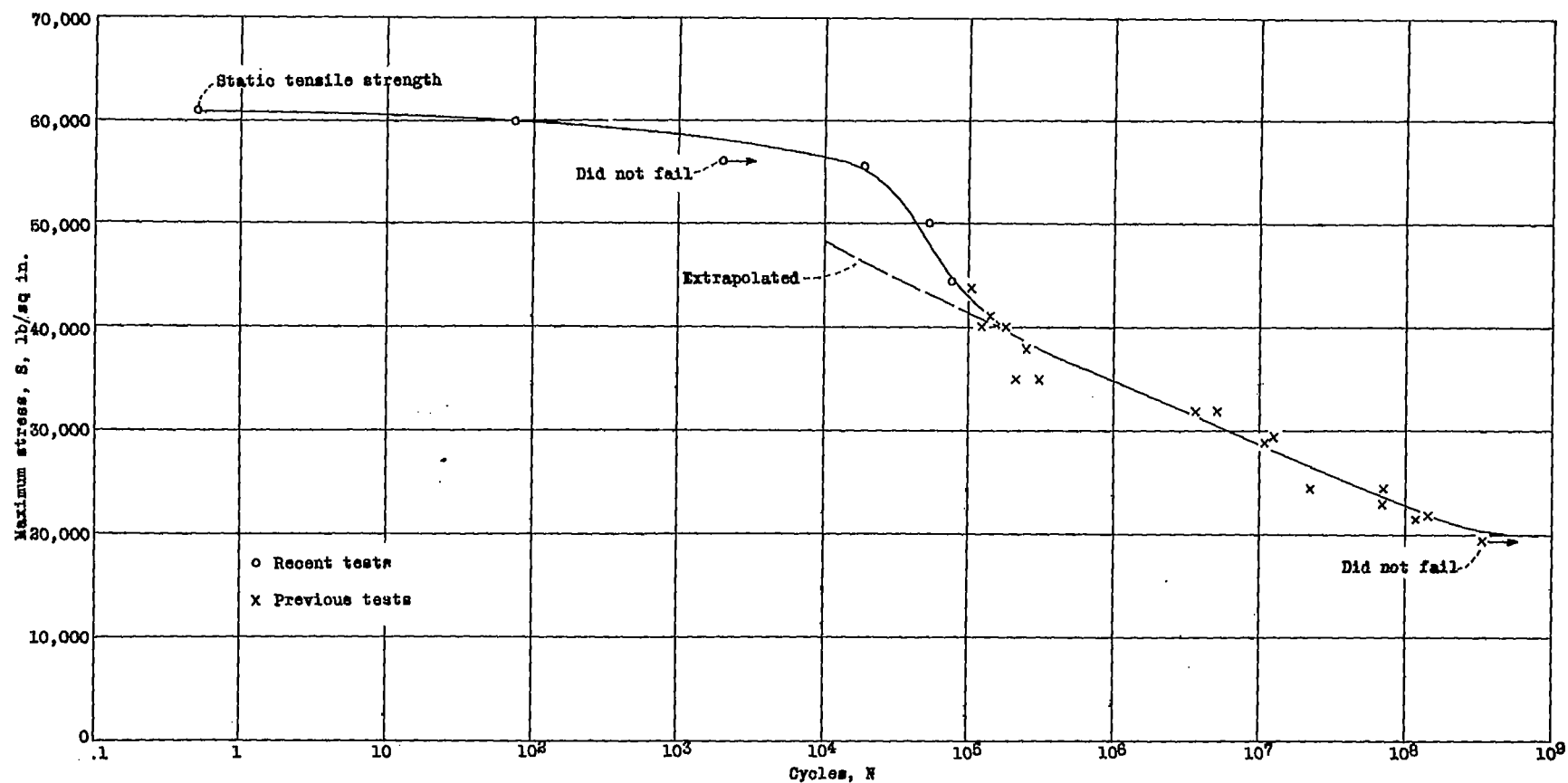to maximum stress is equal to zero.

Figure 4.- Direct-stress fatigue curve for 17S-T aluminum-alloy rod. Nominal ratio of minimum to maximum stress is equal to zero.

Fig. 4